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Completed Research Paper

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Abstract

Realizing the potential of digital technologies in hospital care requires collaborative innovation among multiple actors both within and beyond hospitals. Our research investigates the question: what does it take to foster collaborative innovation within a traditionally siloed and closed health information infrastructure? Empirical findings are derived from three cases, which we analyze by focusing on how innovation relates to interfaces with hospitals' information infrastructures. We draw on literature on digital platforms and innovation ecosystems and focus on the notion of boundary resources to characterize these innovation interfaces. While this notion has mainly addressed the concerns of platform owners for 'securing' and 'resourcing' their platforms, our analysis also points to resources related to peripheral actors' needs, specifically 'discovering' and 'vesting' resources. Discovering resources assist innovators in making sense of possibilities and limitations, while vesting resources relate to value appropriation. These resources are crucial for collaborative innovation in existing hospital information infrastructures.

Keywords: Collaborative innovation, information infrastructures, boundary resources, hospitals, healthcare

Introduction

The innovative use of digital technologies in healthcare has the potential to be transformative, but introducing new digital capabilities to existing system landscapes has proven to be very challenging (Fitzgerald, Kruschwitz, Bonnet, & Welch, 2014; Gandhi, 2016; Romanow, Cho, & Straub, 2012). Although innovations in medical devices and clinical procedures revolutionize medical practice, information systems are not keeping pace and inertia creeps into hospitals´ information infrastructure (Afferni, Merone, & Soda, 2018; Spil et al., 2010). The traditionally siloed hospital information systems have gradually become interconnected, making the introduction of novelty challenging, as it involves an immense number of localized and cross-cutting dependencies (Bygstad & Hanseth, 2016; Hopkins & Jenkins, 2008). Nevertheless, renewal and innovation need to be fostered both in clinical practice and operations to meet the triple aim of improving health, enhancing the care experience, and reducing per capita costs (Berwick, Nolan, & Whittington, 2008). Prior research has explored how novelty within such interconnected information system landscapes can be pursued through the evolution of proprietary closed systems (Reimers, Johnston, & Klein, 2014) or by opening up to third parties through infrastructural transformations towards platformization (Bygstad & Hanseth, 2018). Platformization entails establishing boundary resources to serve as interfaces between information systems that were initially developed following a silo logic and novel services catering for local adaptation and innovation (idem).

Outside hospitals, a dynamic innovation ecosystem has emerged where entrepreneurial initiatives promote a privately-driven digital healthcare that utilizes e.g. wearables, self-monitoring and tele-health. Hospital information infrastructures can relate to and benefit from this thriving innovative environment. This can happen by leveraging the dynamics of so-called open or collaborative innovation (Bommert, 2010; Lee, Hwang, & Choi, 2012). By collaborative innovation we refer to innovation trajectories where the resources and the creativity of multiple actors join to enhance the quality, speed and range of outcomes. (Nambisan, 2008). We are interested in actors that come from outside the traditional, R&I-focused parts of the organization or even from actors external to the organization, as both may contribute significantly to innovation. The characteristics of digital technologies, primarily the capabilities for modularization and decoupling, make this easier than ever before. Specifically, the widespread use of web service protocols and APIs increase the level of decoupling. This creates new opportunities for leveraging the dynamics of third-parties; like e.g. Salesforce, SAP and Microsoft do for their product portfolios (Benlian, Kettinger, Sunyaev, & Winkler, 2018). If healthcare organizations should succeed in fostering such collaborative innovation, it will be important for their digital infrastructures to accommodate third-party contributors. This may require adjusting their architectures and governance arrangements, providing boundary resources that cater for the needs of contributors. We here seek to articulate what such an adjustment requires. Our research question is therefore: "what does it take to foster collaborative innovation within a traditionally siloed and closed health information infrastructure?".

As our conceptual frame for the study, we draw on literature on collaborative innovation around digital platforms and innovation ecosystems (Cusumano, 2010; Tiwana, Konsynski, & Bush, 2010). In particular, we employ the notion of boundary resources; capabilities offered by a platform to structure the collaboration between the platform owner and third party complementors (Ghazawneh & Henfridsson, 2013). We extend existing literature on boundary resources by investigating issues that emerge when an existing infrastructure needs to relate to (or accommodate) external innovations. The previous discourse has emphasized the platform owner's perspective. For instance, Ghazawneh and Henfridsson identified two boundary resources that reflect platform owner's concerns for resourcing and securing. They define resourcing as "the process by which the scope and diversity of a platform is enhanced" through providing key resources to third-party developers that then produce software additions (applications) for the platform. Securing is defined as "the process by which the control of a platform and its related services is increased" (Ghazawneh and Henfridsson 2013, p. 176), e.g. through issuing and policing requirements for performance or content. Our study investigates initiatives emerging not from the central infrastructure owner (the "core"), but from actors that are more peripheral. The analysis resulted in the identification of additional types of boundary resources that are of relevance to such third-party actors, which we call "discovering" and "vesting" resources.

Our argument is based on the analysis of longitudinal empirical material from innovation attempts in a hospital context. We selected three concrete innovation initiatives and investigated their requirements for linking with the existing information infrastructure. These three cases represent attempts for collaborative innovation, as they involved clinicians and technology providers that had to cooperate for the innovation to succeed. Moreover, they had to cooperate with the central health information infrastructure provider (which represents the platform owner or 'core'), and thus we label them as 'peripheral actors'. Based on this analysis, we identify novel types of boundary resources that are required for a healthcare information infrastructure to support collaborative innovation. The paper thus contributes to the literature on collaborative digital innovation within complex organizations such as healthcare.

The remainder of the article is structured as follows. First, we lay out prior related research from a) literature on innovation in healthcare organizations, and b) literature on digital platforms with a specific focus on the notion of boundary resources. We then provide an overview of the empirical setting and describe the method used to collect and analyze empirical data. Subsequently, we describe and present our analysis and interpretation centered on articulating the requirements for a health information infrastructure that enable collaborative innovation. Finally, we conclude by discussing insights from our analysis, pointing to the contributions for research and practice.

Related Research

Collaborative innovation in healthcare

Several researchers have called for public sector organization to open up to a broader set of stakeholders in their innovation attempts. Collaborative innovation means that actors from within the organization, other organizations, the private and third sector and citizens are integrated into the innovation cycle (Bommert, 2010; Nambisan, 2008). Nambisan defines collaborative innovation as a "collaborative approach to innovation and problem solving in the public sector that relies on harnessing the resources and the creativity of external networks and communities (including citizen networks as well as networks of nonprofits and private corporations) to amplify or enhance the innovation speed as well as the range and quality of innovation outcomes" (2008: 11). Collaborative innovation is advocated based on the assumption "that the active participation of a wide range of actors with their innovation assets (intangible: knowledge, creativity etc. and tangible: money and other physical assets) will increase the quantity and quality of innovations" (Bommert, 2010).

Collaborative innovation is challenging for hospitals which are complex environments and have traditionally struggled with their networked information exchange and communications (Gupta, 2008; Hanseth & Bygstad, 2015; Leidner, Preston, & Chen, 2010; Nembhard, Alexander, Hoff, & Ramanujam, 2009). Nevertheless, hospital innovation does happen, especially as "engaged people solve little problems that can grow into big initiatives" (Mintzberg, 2017, pp. 28, 194). King and Lakhani (2011) (as cited by Benner & Tushman, 2015) argue that open innovation is to be found when the knowledge needed to create or to select appropriate solutions to a problem is broadly held, while when such knowledge is concentrated internally intrafirm innovation tends to dominate. Salge and colleagues researched 62 innovation projects within the English National Health Service (NHS) and identified cases of successful open innovation initiatives and also issues related to the transfer and internalization of novelty that need to be taken into account before deciding which approach to follow (Salge, Farchi, Barrett, & Dopson, 2013). Overall, prior research has shown that internal actors (from the clinical side or from internal IT departments) can be better placed to identify problems related to clinical practice, to work out suitable solutions using digital technologies and to bring them in use. External actors can be better placed to identify problems related to patient experience having the flexibility to experiment with different solutions.

It is not easy for healthcare information infrastructures to accommodate collaborative innovation. A core hurdle relates to the prioritization of support to the established operational arrangements within hospitals. Research on organizational innovation and transformation emphasizes the crucial role of ambidexterity (literally: the ability to use both hands). The notion refers to the ability to support both exploitation and exploration. Exploration includes search, variation, risk taking, experimentation, flexibility, discovery, innovation while exploitation includes refinement, efficiency, production, implementation, execution (March, 1991). Both are required to keep abreast of technological developments and broader societal goals. While routine operations and continuous improvement of health services are the norm, more exploratory efforts could (and ought to) also happen. Prior research investigated different alternatives on how ambidexterity can be pursued at the structural level within the IT function, e.g. by structural separation from exploitation efforts or by having both exploration and exploitation executed in the same unit (Benner & Tushman, 2015). One of the primary approaches to achieving such a balance is to structurally separate exploration from exploitation (O'Reilly & Tushman, 2013; Tushman & O'Reilly, 1996). Similarly, within IT departments, a bimodal strategy has been proposed, emphasizing separation of IT teams dedicated to efficient IT services (where the focus is on predictability, scalability, risk aversion and cost savings) from those acting like a start-up inside the organization focusing on fast innovation (Badr, 2018; Horlach, Drews, & Schirmer, 2016). A similar recommendation comes from a study of healthcare innovation, which emphasizes the importance of externally driven innovations arguing that "a third-party ecology is more innovative than a heavyweight IT department", because "the solutions of the future are not only hard to plan but also hard to envision, and emerge through interactions of diverse actors" (Bygstad, 2017). Although these studies have investigated the organizational arrangements of the IT function for ambidexterity, they have not elaborated on the architectural configurations that can contribute to ambidexterity.

While the value of collaborative innovation and co-creation is broadly accepted, questions regarding its practical implementation still remain. More knowledge is needed on the requirements for opening up health care information infrastructures to collaborative innovation, and in particular, the question of how to connect the novel digital initiatives with the pre-existing information infrastructure is relevant. To illuminate this further, we look to literature on digital platforms and the notion of boundary resources.

Digital platforms and boundary resources

Digital platforms have proven to be immensely generative of innovation becoming the dominant form for the world's top innovative companies. A platform architecture is comprised of a technological core and peripheral applications (often developed by third parties) that interact through standardized interfaces. For the peripheral application developer, the platform allows a targeted focus on the differentiating value proposition, while key infrastructural resources as well as access to a user base are provided by the platform. A core concern for a platform owner is to balance the interplay between control and generativity; which is a shared concern for all digital infrastructures (Tilson, Lyytinen, & Sorensen, 2010). Ghazawneh and Henfridsson studied how Apple sought to simultaneously control what happens in iPhone´s ecosystem while benefiting from harnessing third-party contributions (Ghazawneh & Henfridsson, 2013). They found that within iPhone´s ecosystem innovations are facilitated and controlled through boundary resources that serve as the interface between the keystone player (i.e. Apple) and third party application providers and showed how multiple providers are orchestrated by configuring boundary resources. They developed a model drawing attention to: a) the aim of keystone players for securing their control and b) their aim for enhancing scope and diversity through third party resourcing. The model suggests that attention to both these drivers is important. The concept of boundary resources allows focusing on the exchanges between core and periphery in infrastructural arrangements beyond platforms. The boundary resources are the key means for exposing and extending the core, as it facilitates peripheral development. According to Ghazawneh and Henfridsson the boundary resources can be both technical and social in nature. For instance, application programming interfaces (APIs) are the most common type of technical boundary resources, while regulations, incentives and guidelines are examples of social boundary resources.

Research on platforms and innovation ecosystems have largely been conducted on "born digital" firms, however, also established firms can succeed in establishing open platforms for collaborative value creation with external complementors and/or customers (Schreieck & Wiesche, 2017). There is less research, however, on these kinds of arrangements within sensitive domains like healthcare where core concerns are to provide safe, effective and efficient services and achieve societal and political goals. This further implies that the governance structure and boundary resources need to align with these wider sets of goals.

We use the term "health information infrastructures" for the hospital application landscapes because we conceptualize them as a subset of the information infrastructure category (Hanseth & Lyytinen, 2010). Information infrastructures are shared, evolving and open providing support to multiple different activities. They are sociotechnical bases to build upon, this implies that they cannot be defined through a distinct set of functions (unlike specific information technology applications), or strict boundaries. They need to cater for a wide range of potential users and uses currently and in the future (Pollock & Williams, 2010). In order to extend the information infrastructures, new technological components need to be introduced not as standalone objects but as elements in the wider infrastructural arrangements (Hanseth & Lyytinen, 2010). Working with infrastructures within healthcare is especially challenging because novelty has to link to historically built landscapes that are the outcome of intensive digitalization efforts undertaken during the last decades (Grisot & Vassilakopoulou, 2015). Overall, much of the value of infrastructures lies in the relationships they embody (Bietz, Baumer, & Lee, 2010). While recognizing that most health information infrastructures today are not (yet) exhibiting a platform architecture, we will employ the notion of boundary resources in a wider sense, as we find it relevant to also conceptualize how an established core within an information infrastructure accommodates novel peripheral components. Through the provision of data, resources and functionality, an established information infrastructure may allow novel ideas to be discovered, developed and implemented in collaborative innovation with external actors.

Research approach: a case study of innovation projects

Our research is based on an embedded case study (Yin, 1994) intended to reveal what it takes to foster collaborative innovation within a traditionally siloed and closed health information infrastructure. The empirical material includes experiences of bringing novelty to an established hospital information infrastructure by linking new peripheral components. The hospital studied offers multidisciplinary rehabilitation to patients with complex functional impairment following illness or injury and has a strong emphasis on research and innovation. We analysed three different initiatives to introduce new services related to information sharing. Following the trajectories of these initiatives, we traced challenges of connecting to the existing infrastructure and identified the requirements for making collaborative innovation possible. In our analysis we zoom-in on the problematic "meeting points" between the innovation initiatives and the pre-existing infrastructure. The three sub-cases make up the embedded case study and reveal the needs and requirements of the peripheral actors that connect to existing infrastructures. In the following paragraphs, information is provided on the hospital's wider organizational context as it pertains to the infrastructure and its governance. Then, the data collection methods and the data analysis strategy are presented.

Case Background: Organizational and infrastructural context

This study was conducted in the Norwegian hospital sector, where hospitals are public and allocated to four independent regional health authorities under the jurisdiction of the Ministry of Health and Care Services. The regional health authority defines the ICT strategy and governs IT service provision, through its IT service provider, HospitalPartner. Overall, the region within which our study is set includes several hospitals with thousands of IT applications forming a fragmented ICT landscape. During the last two decades, the regional health authority implemented a gradually more centralized IT governance regime. Previously, individual hospitals could commission services from the regional IT service provider to support their own innovation projects, today service provision is aligned with centrally defined goals and independent projects are generally not supported. There are five formal requirements from the regional health authority related to IT service provision. These are: a) offer stable service delivery, b) ensure compliance with information security regulations, c) provide cost effective operations d) support prioritized development areas, and e) support regional programs and projects. Support for research and innovation is mentioned, but not prioritized at the level of the other concerns.

Between 2013 and 2017, employees within the IT service provider initiated an effort to establish better support for collaborative innovation utilizing the notion of bimodal IT. This was the InnoCloud initiative. Their presentation of visions for a cloud-based innovation platform that would provide resources such as test data, APIs to core clinical systems and secure and legal storage facilities for sensitive personal health data, was warmly welcomed by both the entrepreneurial and established health IT industry. While the initiative did not manage to mobilize the resources required to actually deliver such a platform, it achieved to raise the general awareness regarding the need for innovation and the shortcomings of the existing health information infrastructure. We aim with our research to investigate the requirements further, in order to potentially inform subsequent efforts to enable and stimulate collaborative innovation.

Data collection and analysis

Our research group has had an established research collaboration with several hospitals in the region since the mid 1990's, and we have collaborated with the selected specialist hospital since 2006, following a number of innovation initiatives during this period. The longitudinal research collaboration has been both ad hoc (e.g. around student projects and smaller, targeted studies) and formally organized in a number of larger research projects and consortia. Both the hospital and the regional trust have been formal project partners in the most current research activities. We thus draw on an extended set of empirical material and have selected a set of sub-cases from among this larger set. The three sub-cases are similar in that they all represent attempts at collaborative innovation, involving actors that were not part of the IT department, i.e. both clinicians and technology vendors. They are also somehow different with respect to who the initiators were, the projects' goals, and demands to the infrastructure. Specifically, the first of the sub-cases was initiated by hospital clinicians and a software company was hired for this purpose. The second sub-case was also initiated internally in the hospital and was based on the repurposing of an existing digital solution that was available on the market but was introduced to healthcare for the first time. The third case was initiated and developed by an external company specializing in healthcare solutions. In Table 1 a brief description of the three selected initiatives is provided, including the key aim for each initiative and a short trajectory overview.

Initiative	Key aim	Trajectory overview
Mobile Movement	Clinician conceptualized a solution for distributed harvesting of sensor data for movement analysis to enable remote patient training and interaction with therapists.	The project successfully gained funding and a prototype for sensor data harvesting and analysis was developed. As a next step, secure data storage and integration with the EPR was needed. Project on hold.
Scheduler	The hospital wished to replace the paper-based distribution of schedule information with a digital tool allowing patients, visitors and staff quick access to updated plans for patients' daily activities (e.g. scheduled treatments, tests).	An existing scheduling solution was repurposed for hospital use by a commercial vendor. A pilot (without integration to the EPR system) was successfully conducted and a scaling strategy designed. Gaining access to the regional infrastructure was challenging and too costly for the vendor, but the system is still used in a non-integrated mode.
Bedside Data Entry Tool	External vendor wished to test a solution enabling clinicians to enter data on the move (to improve efficiency of documentation work and support work optimization).	A prototype was tried out, first in a mockup version then refined. Technical integration with the hospital infrastructure is pursued for pilot implementation (which is ongoing).

Table 1. The set of embedded case studies

Data were collected through formal interviews with the clinical staff and the software vendors involved in the initiatives as peripheral innovators and also, with the staff in the hospital's IT department and hospital project managers.. The interviews sought to illuminate a) the nature of the innovation and its relationship to the wider context including existing systems, b) the various challenges and issues that arose during the development and implementation processes, and c) chosen strategies and lessons learned. In addition, we followed the projects through less formal updates on project progress through conversations with project managers. An important data source were the status reports, project documents and presentations that were reviewed for factual information. Additionally, data were collected during project meetings that were organized every 3 months. The discussions on the constraints and problems perceived by the innovators were presented and the viewpoints and positions of the IT service provider were discussed. Data collection was performed in the 2015-2019 period. In summary, the research reported is based on data collected using a combination of fieldwork and documents' analysis (Table 2).

Interviews	10 interviews with the hospital innovation manager, IT manager and IT workers, project managers (clinicians), external vendors and regional IT service employees
Observations in project meetings and workshops	8 project meetings, 3 full day seminars with project presentations, 1 workshop.
Documents	Emails, project documents. Project documents (technical documents, presentation slides, reports) Region Reports, Region Strategic Planning Documents; Policy, Regulation and Standards Documents

Table 2. Data Sources

For the data analysis, we traced challenges of connecting to the existing infrastructure for peripheral actors that aim to introduce novelty. The analysis of empirical material was performed from an infrastructure perspective informed by the concept of boundary resources (Ghazawneh & Henfridsson, 2013; Hanseth, Monteiro, & Hatling, 1996; Ribes & Finholt, 2009). However, our concern has been to let empirical detail guide the development of insights. Thus, we followed closely the trajectories of the initiatives studied. An initial timeline of events was created and a preliminary narrative on the evolution of the three initiatives was developed. The different episodes were further investigated through document analysis and interview follow-ups. We developed the analysis in an iterative way working with both empirical data and readings from literature. This was followed by a cross-episode analysis to identify common themes across the three initiatives. We analyzed our material to understand how the initiatives met with the existing infrastructure and how they grappled with the related challenges. Our analysis led to the identification of two novel types of boundary resources as perceived by the instigators of the initiatives studied. Our initial empirical studies were exploratory and open, while this paper is based on a retrospective analysis with a specific focus on boundary resources.

Innovation meets Infrastructure

In this section, we present the embedded cases describing their purpose and rationale and the type of infrastructural connections that were required for their realization.

Mobile Movement

In 2015, one of the rehabilitation therapists at the hospital initiated an innovation project, called Mobile Movement. The aim of the project was to develop a digital solution for capturing data on patients' physical movement via accelerometers and sensors positioned on e.g. arms and legs. The data captured would be displayed on an avatar and played back to the patient in real time, visualizing how the performance of the exercise compared to the intended movement pattern. The digital solution would analyze the data providing assessments of training correctness, compliance and efficiency. Also, the data could be sent to mobile phones, and then transmitted to hospital systems, e.g. the clinician's analysis system. This feature allowed distributed data capture via mobile devices, moving away from established procedures that required lab-bound equipment. The solution would help extend the follow-up of patients from hospital labs to the actual everyday patient surroundings, such as their homes or work-spaces. The expectation was that this would enhance patients' training in situations where no therapist was present to guide and remind them. The solution would also gather data on the patients' actual training between consultations. The project received funding from several sources, including the Regional Health Trust's innovation support, and hired a private software development company to develop a prototype in 2015. During the prototyping period, sensor data had been stored on the software company's server, however, in order to proceed to trials with actual patients using the solution, a secure data storage facility was required (complying with regulations on sensitive personal information). The IT service provider at the regional level had plans for offering a secure data storage resource through the InnoCloud initiative, however, at the time it was not available. Other candidate storage resources were investigated. For instance, at the University a new data infrastructure offered secure data storage for research projects. Using the University resources was possible because the project activities could be characterized as research. The use of the University data infrastructure would allow a test with real patients, but it would not be a final solution for running the service for clinical purposes (after the research project). A viable solution would be to ensure secure data storage within the Health Trust's own infrastructure, allowing also relevant data to go automatically to the EPR of the hospital. This would provide the opportunity to explore the value of the data collected for analysis and learning. However, as no support was available, the project was put on hold and the innovative clinician returned to her ordinary work duties in the lab.

The Scheduler

During the spring of 2016 the hospital initiated a trial of a digital scheduling system for inpatient appointments (e.g. for tests, physical exercise, or speech therapy during the day). A digital solution for sharing schedule information was desired, because it could facilitate information updates and distribution, allowing patients to look up their schedules on their own devices (e.g. mobile phones). Ideally, patients' visitors could also access the schedules before coming to the hospital and time their visits accordingly. The established routines entailed printing multiple copies of the schedules every day and distributing them across the hospital. A trial of a digital schedule solution was initiated after a chance contact with a vendor which was already a market leader in scheduling solutions for higher education, offering functionality for room booking and schedule planning. The company was interested in entering the healthcare sector; the planning of multiple patients' access to fixed resources (e.g. examination labs) was seen to have enough similarities with the education application domain to warrant a try. The company was invited to run a trial implementation of their solution. Since the solution was already developed, the main effort was related primarily to setup and adaptation to organizational processes. Technically, the system was run from the vendor's cloud infrastructure, with the servers located in a neighboring country. The system was built with capacity for integration with other systems (e.g. student administration systems and resource planning systems in educational institutions), however, in the hospital the pre-existing systems (most notably the Electronic Patient Record) were not built for integration. Even though this was a technically solvable problem, actual integration was ruled out because the health sector's privacy requirements would not allow the release of sensitive information to an application running on a foreign cloud infrastructure. Thus, in the trial period the scheduling solution was not integrated with the core hospital systems and was used with anonymized data (e.g. room numbers instead of patient names as identifiers). The system was allowed to run only in the internal secure network, meaning that family and relatives could not access the patient's plans, as was initially intended. The system itself worked fine and improved the planning work. Also the patients reported more satisfaction and experienced more participation in their care process. The vendor was given the choice of either developing a server side application that could run on the regional infrastructure (i.e., inside the firewall), or to upgrade its cloud-based infrastructure significantly to comply with existing policies. The work required was too costly for the vendor who decided against this. The use continued with the anonymous data and without digital integration, as it was deemed to be too useful to stop its use.

The Bedside Data Entry tool

In December 2017, a small start-up company asked for collaboration with the hospital. They wished to develop and validate a prototype for a mobile tool that would simplify the work of clinical documentation and communication. The innovators had already developed an early prototype based on their own work experience in the health sector and a series of systematic observations at emergency wards at several hospitals. Now the innovators needed to verify the feasibility of the tool and to collect initial data on its efficacy and efficiency. The hospital welcomed the innovators from the small start-up, and set-up a workflow simulation exercise. During this exercise, clinical workers performed a specific list of tasks measuring the time needed for task completion with and without the use of the mobile clinical documentation tool. The simulation generated evidence that was used to calculate the potential for time savings. As an outcome of the initial collaboration, the hospital decided to continue with the prototype development aiming to deploy the tool. For this, integration with the existing information infrastructure was needed. Specifically, patient data had to be extracted from the Electronic Patient Record (EPR) system, which holds the most relevant information about patients. Also, data entered in the new tool had to be transmitted and registered to the EPR system – this would alleviate the need to physically go to the ward office to document. A description of the EPR API was provided by the EPR vendor on request and allowed the start-up company to develop the integration. After that, the data transmission to and from the EPR system had to be tested to see whether data were correctly transferred between the two systems. However, test data were not available. When IT service provider was running tests, copies of production data from the hospitals served, were used. However, such data could not legally be made available for an external actor. The hospital had to make a formal purchase of the tool, which changed the status of the start-up company making it possible to perform tests using copies of the hospital's real data. However, also this came with practical restrictions in the company's ability to run the testing, as they had to be on-site in the hospital rather in their own premises. In addition, the tool had to use the identification and access management (IAM) solution of the IT service provider. Furthermore, several formal steps were required, such as preparing a concept description and a risk and vulnerability analysis. The start-up company commissioned and paid for the requested risk and vulnerability analysis from an independent firm. While the process has been slow, the cooperation is ongoing and the application has moved into pilot deployment. Currently, the application is installed on a server within the secure zone, the remaining development is coordinated from the hospital side, and the IT service provider at the regional level makes efforts to respond in an agile manner to the change requests emerging from testing and development (for instance, by changing the established 3 months' long change cycles). However, the division of responsibility between the ERP vendor, the hospital and the IT service provider at the regional level has not always been clear.

Analysis: Types of Boundary Resources for Collaborative Innovation

We will now relate the issues encountered by the actors that aimed to expand the existing infrastructure by linking new peripheral components (internal or external innovators), to requirements for boundary resources. Boundary resources are understood as the core infrastructure's (i.e., keystone player's) response to external contribution opportunities and control concerns. Our findings show the critical role of boundary resources for the introduction of novel digital services and their embedding into the pre-existing information infrastructure. Boundary resources serve as the interface between the core systems that are part of hospital infrastructures (e.g. Electronic Patient Record Systems) and new external applications that need to connect and build upon the capabilities of these core systems. They are the means for exposing the infrastructure core to facilitate peripheral development.

Boundary resources - the perspectives from the core and the periphery

Looking at the keystone player´s concerns, Ghazawneh & Henfridsson (2013) identified two types of boundary resources: securing resources (that aim to increase control) and resourcing (that aim to enhance scope and diversity). If we map these to the cases studied we see that the concerns of the keystone player (regional health authority/IT service provider) map well to these two types of boundary resources, in particular the securing type. Furthermore, the cases revealed that the innovators have their own requirements towards the infrastructure. Two additional types of required boundary resources were identified, which we call Discovering and Vesting resources. Discovering resources allow periphery actors to make sense of the possibilities and limitations of the infrastructural core, ensuring some level of visibility into it. Vesting resources relate to arrangements for the appropriation of benefits that come out of the new peripheral components, e.g. related to rights for exploiting new data, functionality restrictions or limits, etc.

The trajectories of the three initiatives show that in the hospital under study it was possible to conceptualize and to develop proof of concept solutions for novel digital services. What proved to be very challenging, was taking them a step further, allowing the new solutions to leverage the existing infrastructure. The further development and testing of the new peripheral applications encountered significant obstacles. Furthermore, the novel solutions could not benefit from the infrastructural dynamics because the peripheral actors were not vested with rights for leveraging existing infrastructural components or for deploying their solutions for other users within other hospitals currently sharing the same overall infrastructure. Table 3 provides an overview of the boundary resources needed.

The perspective from the core		
	Securing Boundary Resources	**Resourcing Boundary Resources**
Mobile Movement	Regulation prohibits un-authorized storage of health data, which stops the trial (sensitive data is then neither generated nor stored).	Boundary resource of secure data storage was planned but not provided (because regional resources prioritized core systems).
Scheduler	Protecting sensitive data (EPR information) - controlled cloud solution. Requiring the application to run within the secure environment, not in the cloud. Regulation-based rather than technology-based securing.	External solutions are only allowed to run within the secure infrastructure (requiring compliance with architecture). The Region required "securing" but did not offer resources to enable it (responsibility of compliance lies with vendor).
Bedside Data Entry	Requiring formal process for access to health data, and requiring integration with/use of IAM solution (Identity and Access Management) and MDM (Mobile Device Management).	Provided APIs to EPR system and IAM functionality. Access to test data
The perspective from the periphery		
	Vesting Boundary Resources	**Discovering Boundary Resources**
Mobile Movement	Initiative offers a potential resource for users: easier recording of information, more realistic	Need to make sense of capabilities for secure storage of measurements now and in the

	recording, additional amount of data recorded. Requires sharing decisions regarding data ownership and management issues.	near future. Also, visibility into analysis capabilities is required for further development.
Scheduler	The new tool allows the vendor to expand in the healthcare sector but it has to incur all costs related to linking with the existing infrastructure. Not clear if it would be possible to appropriate benefits beyond a single hospital to compensate for this.	Need to use the possibilities offered by EPR systems regarding demographic and logistics information. Not having this access implied double work of manually copying information and also limited generativity of new types of functions.
Bedside Data Entry	Ensuring more efficient information capture and use in wards also allows reusing data (based on employee consent) for analysis and learning. This requires decisions regarding data ownership and management.	Need to be able to test/operate against the concrete production configuration (not a test instance) but lacked (initially) test data available to third parties. Desired resource: Services for real life testing, Access to realistic or real data and user community.

Table 3. Securing, Resourcing, Vesting and Discovering Boundary Resources

Drawing from our findings, we supplement the two types of resources identified by Ghazawneh and Henfridsson (2013) adding two more that reflect the needs of peripheral actors and complement the types of resources that reflect the concerns of those that control the core hospital infrastructure. Periphery actors need to make sense of the possibilities and limitations of the core, ensuring some level of visibility into it and to ensure rights for leveraging the existing infrastructure or the new data streams. Figure 1 provides an overview of the different types of boundary resources.

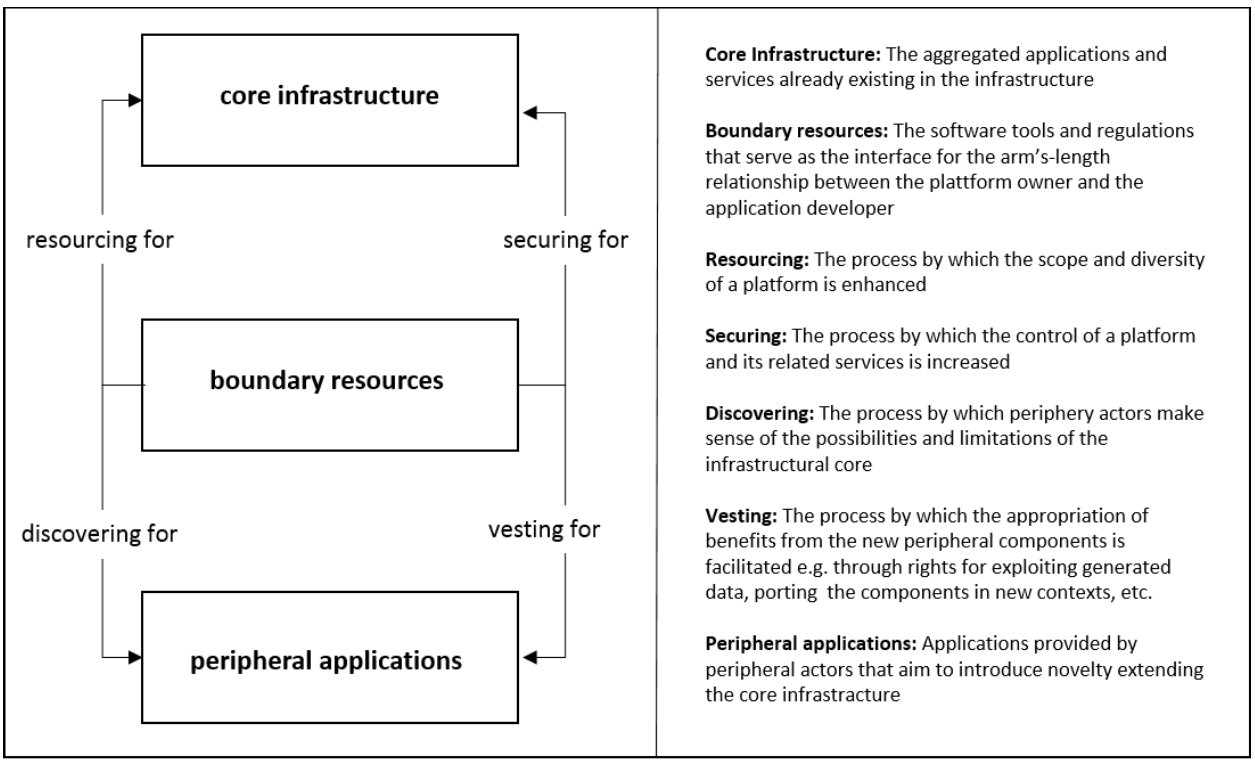

Figure 1. Different types of boundary resources: the views from the core and the periphery

The further development of the IT provider's response indicates the relevance of our analysis. Although the InnoCloud initiative did not manage to resolve the practical issues faced by innovators, the IT service provider clearly recognized the need to support innovators. This aim was included in the regional Innovation Plan for 2016/2017. In that period, there were preparations for outsourcing parts of the IT infrastructure, and the expectations were that this could resolve some of the challenges. During 2017 and the first half of 2018, a concept development process led to a solution that was intended to facilitate innovation, however, primarily addressed internal research and innovation activities (i.e. it was not conceptualized as an open resource for the wider community of external vendors and innovators). A new service platform was described, which should provide i) data access services to core information sources (EPR system, medication chart, specialist EPR systems, population registry), ii) integration of data access services to the identity management and access control services in the region, and iii) security services adapted to both actual and synthetic patient information for test purposes. This new service platform would require the building of new organizational capabilities in the IT service provider, an adequate security regime, and an active approach to contractual aspects (e.g. actively managing data provider agreements with all vendors). Furthermore, the hospitals require a technical verification service for applications and services to ensure that they can scale without adverse security or performance consequences, and they also require support with the contractual and commercial handling of projects and agreements regarding experimental and innovative procurements. Testing requires the establishment and management of the required interfaces including maintenance and updating, a cost-splitting model, and practical access handling to the test resources. This shows that also "periphery-oriented" boundary resources are being provided here.

Discussion and Conclusion

In this section we return to our research question, which is *what does it take to foster collaborative innovation within a traditionally siloed and closed health information infrastructure*?

We addressed this research question through an empirical investigation that identified the characteristics a healthcare information infrastructure should contain in order to enable and encourage collaborative innovation. Through our investigation, using the information infrastructure perspective, we provide two contributions, both related to what we call collaborative innovation. The contributions are structured in two sections.

From platform-related to infrastructure-related boundary resources

Earlier research demonstrated that realizing the potential of digital technologies for transforming healthcare is challenging (Gandhi, 2016; Romanow, Cho, & Straub, 2012). Our research confirms this, however, we have gone more in-depth into the question of how operators of healthcare information systems can think if they wish to complement the primary focus on assuring reliable operations by also accommodating collaborative innovation. A significant part of innovative development in digital healthcare happens outside hospitals (for instance, developments that utilize e.g. wearables, self-monitoring and tele-health), and it is desirable that hospitals can relate to and benefit from this thriving environment. To realize this kind of collaborative innovation there is a need to re-configure the existing information infrastructures, which tend to be siloed and closed. Focusing to the interface between the infrastructural core and the periphery, our study complements prior research which addresses mostly the concerns of keystone players (Dal Bianco, Myllärniemi, Komssi, & Raatikainen, 2014; Eaton, Elaluf-Calderwood, Sorensen, & Yoo, 2015; Ghazawneh & Henfridsson, 2013). While platform architectures represents paradigmatic core-periphery constellations, we have here discussed the interaction between infrastructural core and periphery more generally, as we add the perspective of actors that aim to link new peripheral components to an existing infrastructure core. Specifically, we extend the concept of boundary resources to include also types of resources that relate to the needs of peripheral actors (discovering and vesting resources) going beyond the concerns for securing and resourcing. The paper thus contributes to the literature on digital ecosystems, as well as to the understanding of innovation and transformation processes within complex organizations such as healthcare as we seek to define the requirements to a transformation-able healthcare information infrastructure.

As shown in the initiatives studied, novel services may emerge out of problem-solving activities in practice. This may also be facilitated by repurposing and transferring solutions and services used in other contexts and settings as in the case of the Scheduler. However, the introduction of novelty in everyday practice entails moving beyond successful solution demonstrations towards deploying the new technological solutions not as standalone objects, but as elements in larger infrastructural arrangements (Hanseth and Lyytinen 2010). The inherent capabilities of new digital technologies make it possible to leverage existing arrangements for new services creating a wealth of possibilities for supporting healthcare operations and information exchange but this is far from straightforward. Working with infrastructures within healthcare is challenging because of the entrenched roles within the historically built infrastructural landscapes (Grisot & Vassilakopoulou, 2015). Analysing the interface between the infrastructural core and the periphery from both the keystone player´s perspective (governing the core) and the complementor´s perspective (aiming to link peripheral components) allows us to provide a comprehensive foundation for addressing the challenges of introducing novelty within hospitals extending their infrastructures.

From ambidextrous organizations to collaborative innovation in information infrastructures that support exploitation and exploration

The paper also contributes with practical implications, related to the discourse on collaborative innovation in the public sector (Bommert, 2010; Nambisan, 2008). While earlier research identified the need for ambidexterity, or in other words, the need to balance exploitation (routine operations) and exploration (renewal, innovation), we have operationalized this by identifying the architectural configurations that can contribute to such ambidexterity. Adequate provision of a rich set of boundary resources is key in this respect. A real-life resource provision to support third-party innovation will most likely include access to core APIs for data transfer to and from core applications in the health information infrastructure, access to secure data storage for external apps, access to realistic (or real) health data for testing purposes, provision of identification and access management services. Much of this will be contextually shaped, e.g. by the regulatory environment, such as who is allowed to register, store and process personal health data.

Realizing collaborative innovation in healthcare not only requires each organization to be ambidextrous – also the overall ecosystem must be able to simultaneously exploit and explore. We argue that the requirements for such exploitation and exploration differ between the actors within the ecosystem. The keystone players aim for exploration through providing resourcing boundary resources that attract novelty and innovation from other partners. Similarly, they pursue exploitation via providing securing resources that ensure that core operations proceed unaffected by potentially problematic innovations from the external partners. Complementors aim for exploration via discovering resources that allow them to establish novel services and value creation mechanisms, and they aim for exploitation via utilizing vesting resources that ensure that they can operate and continue profiting from their developments in a sustainable way. Our proposal is that by introducing the required boundary resources to facilitate innovation initiatives, an ecosystem-level ambidexterity can be achieved, in addition to organizational ambidexterity. Due to the inherent capabilities of new digital technologies (e.g. for resource pooling, recombination, and extensibility), it is possible to leverage existing arrangements for new services creating a wealth of possibilities for supporting healthcare operations and information exchange. Public healthcare systems can then work in tandem with peripheral innovators' new services which will able to debut quickly, allowing for quick responses to needs, cultivating a venturing orientation, and an accelerated cycle for ideas that once took months or years to be built and deployed. In this way, the potential of collaborative innovation can be realized for the benefit of the wider society.

The insights we derived from the three cases point to the importance of making available specific types of boundary resources that meet the needs of peripheral actors. Further research can investigate how the requirements for such resources may vary depending on the type of digital health technology in question, or on the structural and regulatory characteristics of different healthcare systems. Digital technologies differ in terms of integration within healthcare information infrastructures, in terms of coupling and interaction frequency. For instance, novel solutions used by patients who occasionally wish to show their data to health personnel may work with a one-way information transfer. For such innovation concepts, the "discovering" boundary resources needed can be very limited. On the other end of the spectrum, novel solutions that aim to become part of everyday hospital workflows, such as the bedside data-entry solution, require real-time and two-way integration. For such solutions, extensive "discovering" resources are key. Opening up current siloed and closed health information infrastructures to collaborative innovation is required for leveraging the potential of digital technologies. Prior research on collaborative innovation around digital platforms has pointed to the importance of boundary resources in core-periphery configurations. Our study shows that boundary resources are relevant for architectural configurations that do not necessarily follow the platform pattern but involve an existing core infrastructure that needs to relate to (or accommodate) external innovations.

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